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DEVELOPMENT AND TESTING OF THE AUTOMATED FLUID INTERFACE SYSTEM

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ABSTRACT

The Automated Fluid Interface System (AFIS) is an advanced development program aimed at becoming the standard interface for satellite servicing for years to come. The AFIS will be capable of transferring propellants, fluids, gasses, power and cryogens from a tanker to an orbiting satellite. The AFIS program currently under consideration is a joint venture between the NASA/Marshall Space Flight Center and Moog, Inc. An engineering model has been built and is undergoing development testing to investigate the mechanism's abilities.

INTRODUCTION AND BACKGROUND

The overall goal of the AFIS program is to develop and demonstrate a system capable of making multiple fluid and electrical connections between two docked spacecraft. This system would become the standard interface for satellite servicing and other similar applications. The end goal of the program is to build a flight qualified AFIS and demonstrate its capability on-orbit.

The primary mission of the AFIS is to resupply consumables to on-orbit satellites. This technology could greatly increase the life and flexibility of future satellites. Other possible applications could include space station systems, space based engines, and on-orbit integration of space systems too large to launch as a single unit.

The AFIS was initially developed to be a flight experiment as part of the Satellite Servicer System (SSS). The AFIS has been delivered to MSFC and technically evaluated. As a result of this evaluation, follow-on testing is being conducted at the MSFC and is the subject of this paper. The SSS program was canceled but the AFIS development is continuing.

DESIGN REQUIREMENTS

In order to meet the objectives of providing a flexible system for satellite servicing, the following requirements were imposed:

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- Compatible with both the Orbital Maneuvering Vehicle (OMV) and the Orbital Spacecraft Consumables Resupply System (OSCRS) tanker.
- Compatible with both existing docking mechanisms; the Three Point Docking Mechanism (TPDM), and the Remote Grapple Docking Mechanism (RGDM). (Spacecraft would be docked before transfer would take place).
- Accommodate final engagement compliance.
- Reusable for launched servicing activities to all orbits.
- Life of forty missions.
- Minimize life cycle costs and maximize safety and reliability.
- Carry loads resulting from fluid transfer (2000 pounds total).
- Provide coupling contamination protection as well as separation between oxidizer and fuel couplings.
- Minimize hardware and moving parts on spacecraft side.
- Allow for a standard footprint for all spacecraft.
- Reconfigurable for monopropellant, bipropellant or cryogenic supply.

DESCRIPTION

The AFIS utilizes technology previously developed for a system called the Automated Umbilical Connector (AUC). The AUC was used by NASA/Johnson Space Center to demonstrate cryogenic resupply.

The AFIS is comprised of an active and passive side. The active side is on the tanker and the passive side is on the spacecraft. Both sides are octagon shaped and measure 26 inches across the flats. The active side weighs approximately 36 pounds and the passive side weighs 17 pounds without couplings. Figure 1 shows both sides of the AFIS positioned and ready for engagement. This initial alignment is done by the docking mechanism.

Figure 2 depicts an exploded view of the active side of the AFIS. This side contains all components requiring electrical power and/or control and is comprised of a chassis and a carriage assembly. The chassis is hard mounted to the spacecraft structure, provides a structure for the carriage assembly to ride on, and contains a rotating cover which protects the couplings.

The main component of the carriage assembly is an electromechanical actuator that powers and controls all AFIS functions. This actuator is responsible for the following tasks:

- Rotates covers on both the spacecraft and tanker side.
- Locks/unlocks the two sides together.
- Engages/disengages couplings and connectors.
- Aligns the tanker and spacecraft sides of AFIS.
- Carries the loads from fluid transfer.

The carriage assembly also contains the couplings and connectors. This assembly is stiffened by a truss assembly and is compliantly mounted to the chassis assembly. The compliant mounting allows the AFIS to adjust for misalignments resulting from the docking mechanism.

The passive side of the AFIS is shown in Figure 3. It was designed to be as simple and lightweight as possible and to require no power or control. Moving parts are limited to a rotating cover which is rotated by the active side.

The operation of the AFIS is controlled by three signals: "Enable", "Engage", and "Disengage". The AFIS has redundant electronics and motors which are selected by choosing different channels. When the AFIS is disengaged, as shown in Figure 4a, the carriage assembly is preloaded against the back of the rotating covers. This allows the floating carriage to withstand the necessary vibration loads. When the "engage" command is received by the actuator, a square shaft is extended across the interface as shown in Figure 4b. Once this actuator is fully extended, it has protruded into the center hub of the passive side. The actuator then rotates 45 degrees which rotates both covers and locks the two sides together. The two halves are locked together by having the square end of the actuator rod rotated 45 degrees from the square center hub hole. The actuator then begins retracting. Because the end of the actuator is now fixed, the carriage assembly of the active side (with couplings) begins to move across the interface towards the passive side. The engagement is complete when all couplings are engaged as is shown in Figure 4c. Disengagement is the reverse of engagement.

DEVELOPMENT TESTING

In order to fully understand the characteristics of the AFIS and determine the acceptability of the design, a full series of development tests are being conducted at the MSFC. These include:

Functional Checkout

Upon receipt of the AFIS engineering model, it was functionally checked out to assure the design requirements were fully satisfied. The AFIS performed well and adequately satisfied all requirements. Figure 5 shows the AFIS in the disengaged and engaged configurations while mounted in a structure which simulated a docked spacecraft. This structure also provided the means to introduce misalignments. The AFIS easily performed with all required misalignments.

A major mishap did occur during this phase of the testing. The square end of the actuator rod did not disengage from the center hub of the passive half during disengagement operations. As a result, the AFIS was damaged. The AFIS was repaired and this problem has not reoccurred.

Demonstration Docking and Fluid Transfer

In order to evaluate the compatibility of AFIS with the three point docking system and the ability of the AFIS to transfer fluids, a demonstration docking and engagement was accomplished in the flight robotics facility of the MSFC. The active side was integrated into the Orbital Maneuvering Vehicle (OMV) mock-up. This mock-up was stationary and contained a working Three Point Docking Mechanism (TPDM). This mounting arrangement is shown in Figure 5. A truss structure and tubular frame were used to attach the AFIS.

The passive side of the AFIS was mounted on a mobile cart which contained a trunnion arrangement compatible with the TPDM. The mobile cart floated on air bearings and was propelled by air thrusters. The test apparatus is shown in Figure 6. The mobile cart was flown in and docked to the OMV mock-up using a Automatic Rendezvous and Docking system developed at the MSFC. Once docked, the AFIS was engaged and power and air were successfully transferred across the interface.

This demonstration placed the AFIS in the horizontal orientation. Because the AFIS was designed for microgravity, several changes were required for this test. Even with these changes, the actuator sag prevented any misalignment studies during this demonstration.

This test successfully demonstrated that the AFIS can be integrated with the TPDM. It also demonstrated gas and power transfer across the interface. The AFIS performed well even in the horizontal orientation and with the excessive tolerances inherent with the experimental hardware.

Load Test

A primary concern with the AFIS is the amount of force transmitted back to the spacecraft. A load test is planned which will evaluate this. The passive side of the AFIS is mounted to a load frame and is integrated into the spacecraft simulator used for the functional checkout. The loads transferred back to the spacecraft and tanker are expected to be small. The loads measured will be those caused by the mechanisms engagement. Fluid transfer loads are carried internally by the AFIS. This test will also provide additional information on the effects of misalignment on the AFIS.

Thermal Vacuum Test

The objective of the thermal vacuum test is to examine the AFIS in an on-orbit configuration. Both the active and passive sides will be thermally isolated from the space environment except for the front mounting plates and rotating covers. Before docking, both sides will be independently subjected to the extreme temperature variations of space. This will result in the active and passive sides being at different temperatures. In order to assimilate these conditions a special test fixture was required.

This test fixture includes four basic components: the test support structure, a translational system, solar lamps, and the AFIS support structure including the mechanical stops (Figure 8). The test support structure is a tubular frame approximately eight feet long. It encompasses all testing hardware and provides an interface with the vacuum chamber.

The translation system provides a means of separating the active and passive sides for independent thermal conditioning (Figure 9). The system is made up of several components including: a single axis linear translation table, stepper motor, and the computer hardware necessary for operations. This system is operated remotely by compumotor and personal computer.

The AFIS support structure simulates the tanker and the spacecraft in that they provide a mounting structure and thermal protection for the AFIS (Figure 10). The upper/passive side attaches to the test support structure. The lower/active side is connected to the translation table and has a bank of eleven solar lamps cantilevered to one side to heat the upper/passive half during testing. These solar lamps simulate on-orbit solar heating. They have a lighted length of ten inches giving a maximum temperature on a target surface of 375 degrees F. The lower/active half is heated by a second bank of eleven solar lamps located on the test support structure. Both AFIS support structures contain two lamps to maintain ambient temperature within the enclosures. Also included in the AFIS support structure are the mechanical stops which keep the lower/active support structure from being pulled upward during the AFIS engagement.

This hardware provides the means to simulate an on-orbit AFIS engagement. In addition to this engagement test the transfer of power, cryogens and gas will be demonstrated. Alignment studies will also be a part of this thermal vacuum testing.

Vibration Test

When launched into orbit, the AFIS will be subjected to a severe vibration environment. In order to evaluate the effect of launch and landing on AFIS, a vibration test will be done. A shaker table at the MSFC will be used to conduct the test. Each half of the AFIS will be tested independently.

The test will consist of a sine sweep and random vibration test. The sine sweep will determine the natural frequencies and modes for the mechanism. The random vibration test will determine the mechanisms response to the launch environment. These tests will also provide information on the internal stresses of the AFIS. Initial analysis has already shown that the mounting plate for the Type I half may require stiffening and will be verified.

SUMMARY

A design for an Automated Fluid Interface System (AFIS) which can meet the challenge of satellite servicing has been successfully developed. The AFIS is very flexible in that it lends itself very easily to a variety of spacecraft, tankers, launch vehicles and fluids. The AFIS is capable of monopropellant, bipropellant or cryogenic supply. Up to twenty couplings can be used and can be sized up to 6 inches in diameter. The couplings can easily be reconfigured on the AFIS for various missions. The AFIS design is redundant, reliable, and simple. The passive side of the AFIS is very simple and light weight making it very attractive for satellites requiring fluid or cryogen resupply.

At least two improvements are necessary with the current design. The issue of emergency separation was not addressed. If the actuator fails or the actuator rod does not unlock from the spacecraft side, the two spacecraft will be stuck together, possibly causing the loss of both vehicles. It would not be very difficult to include a means of emergency separation with the current design. Another weakness of the current AFIS is in the locating mechanism of the rotating covers. In one instance, the cover did not lock in the proper position and a coupling snagged the cover during engagement. Only operator awareness prevented any damage from being done. Another possible improvement would be the availability of additional feedback during operation. This is very important in the robotics operation of spacecraft where visual feedback is limited.

Additional Testing of the AFIS will provide the required experience and knowledge for the development of specifications for flight unit procurement.

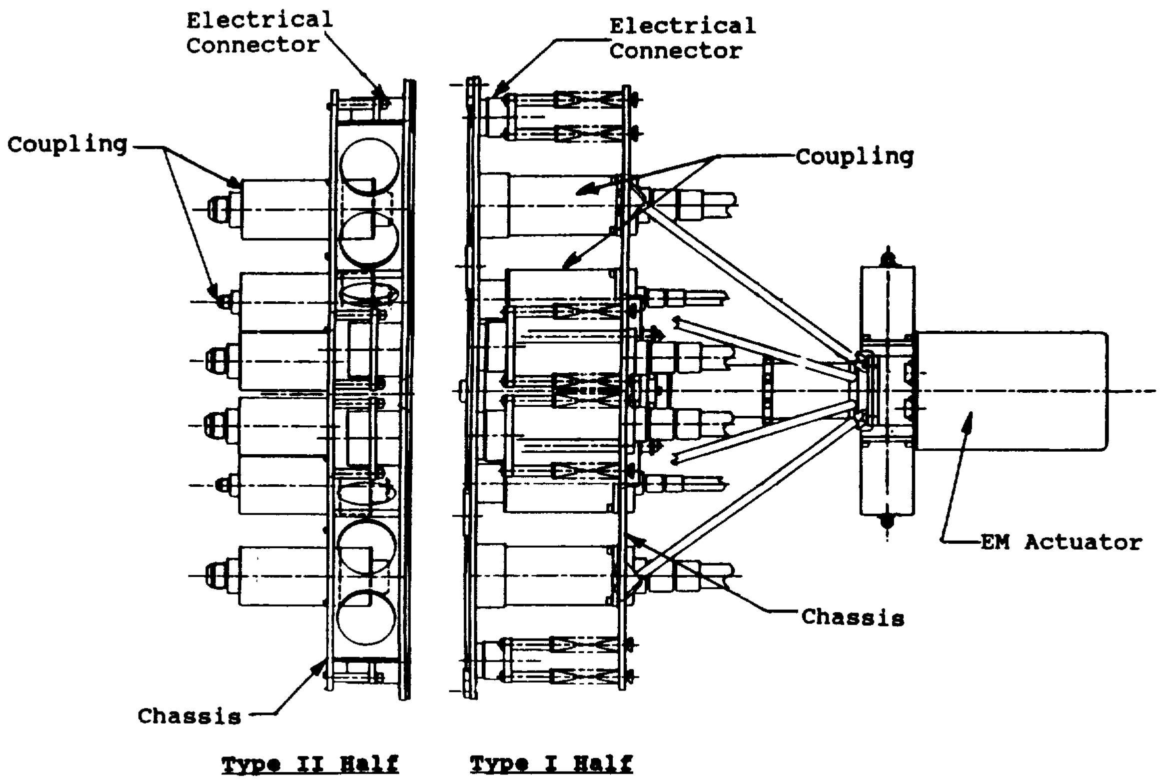

Figure 1: Moog AFIS

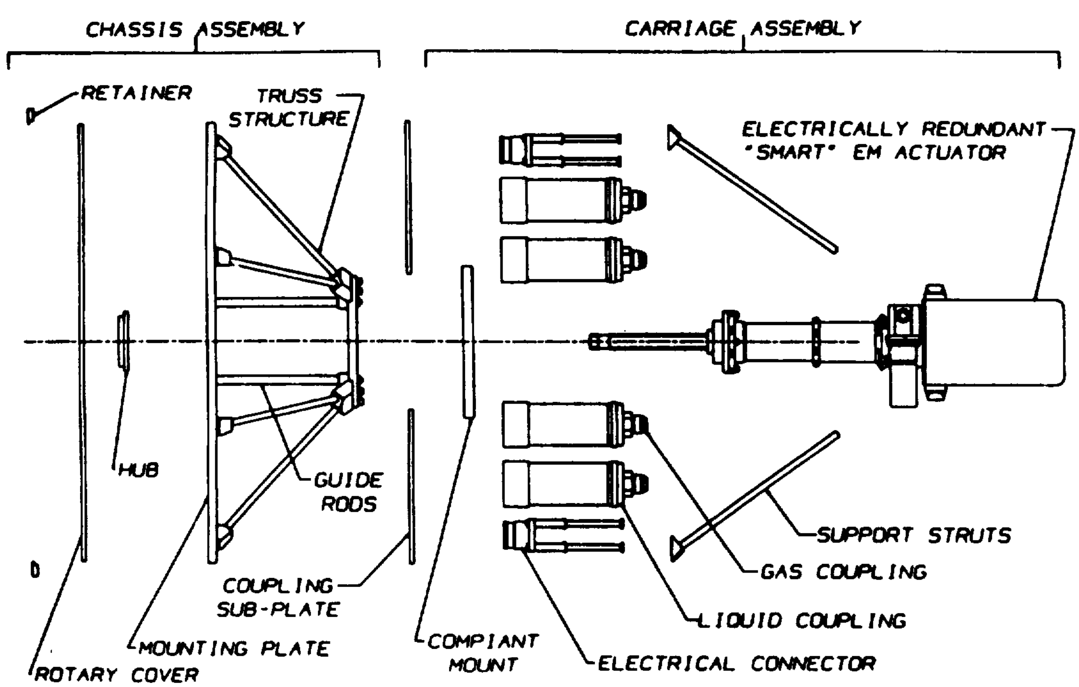

Figure 2: Type I Half of AFIS.

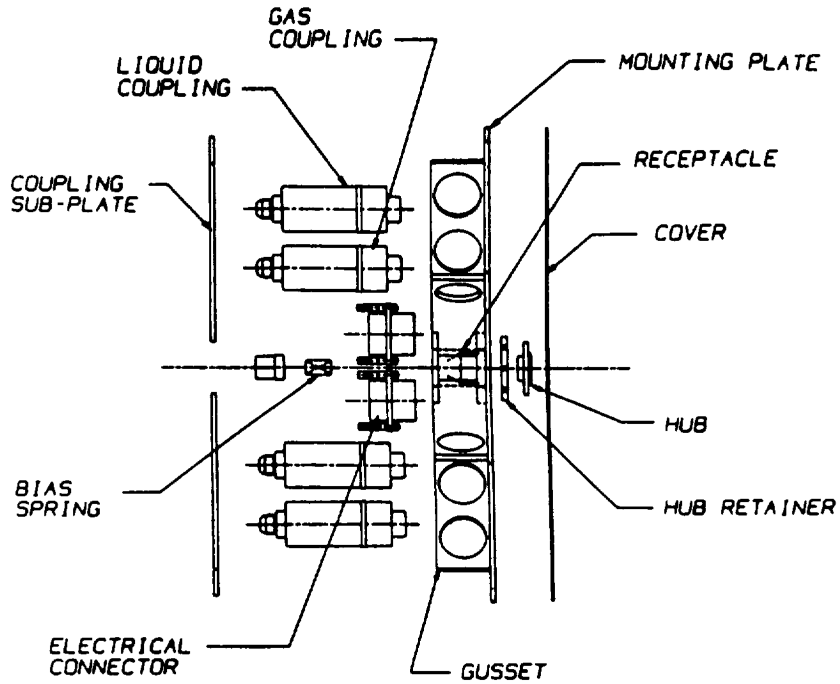

Figure 3: Type II Half of AFIS.

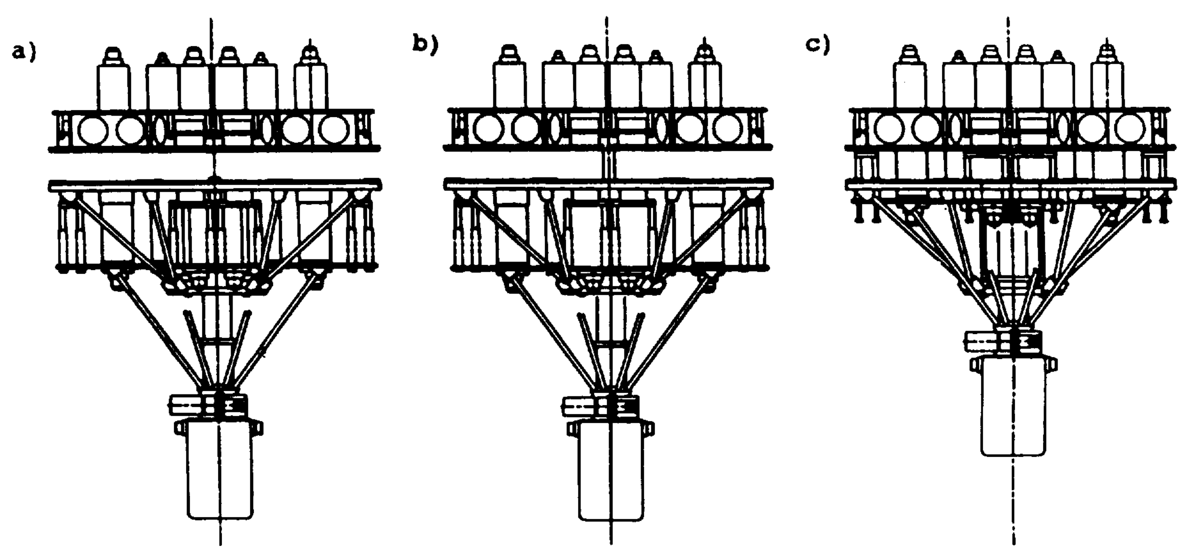

Figure 4: a) Disengaged, b) Actuator Extended, c) Engaged.

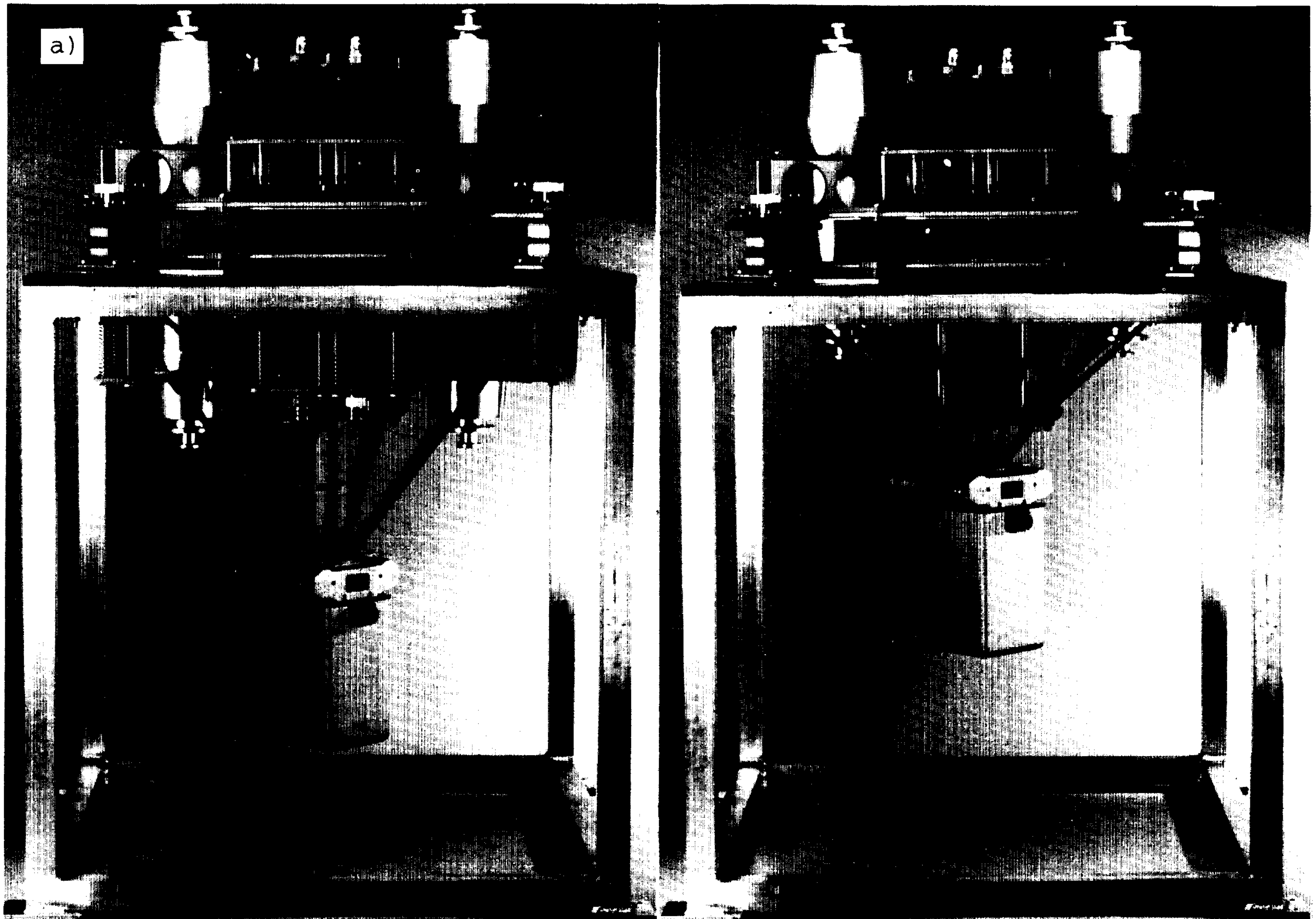

Figure 5: AFIS and Spacecraft Simulator a) Disengaged and b) Engaged.

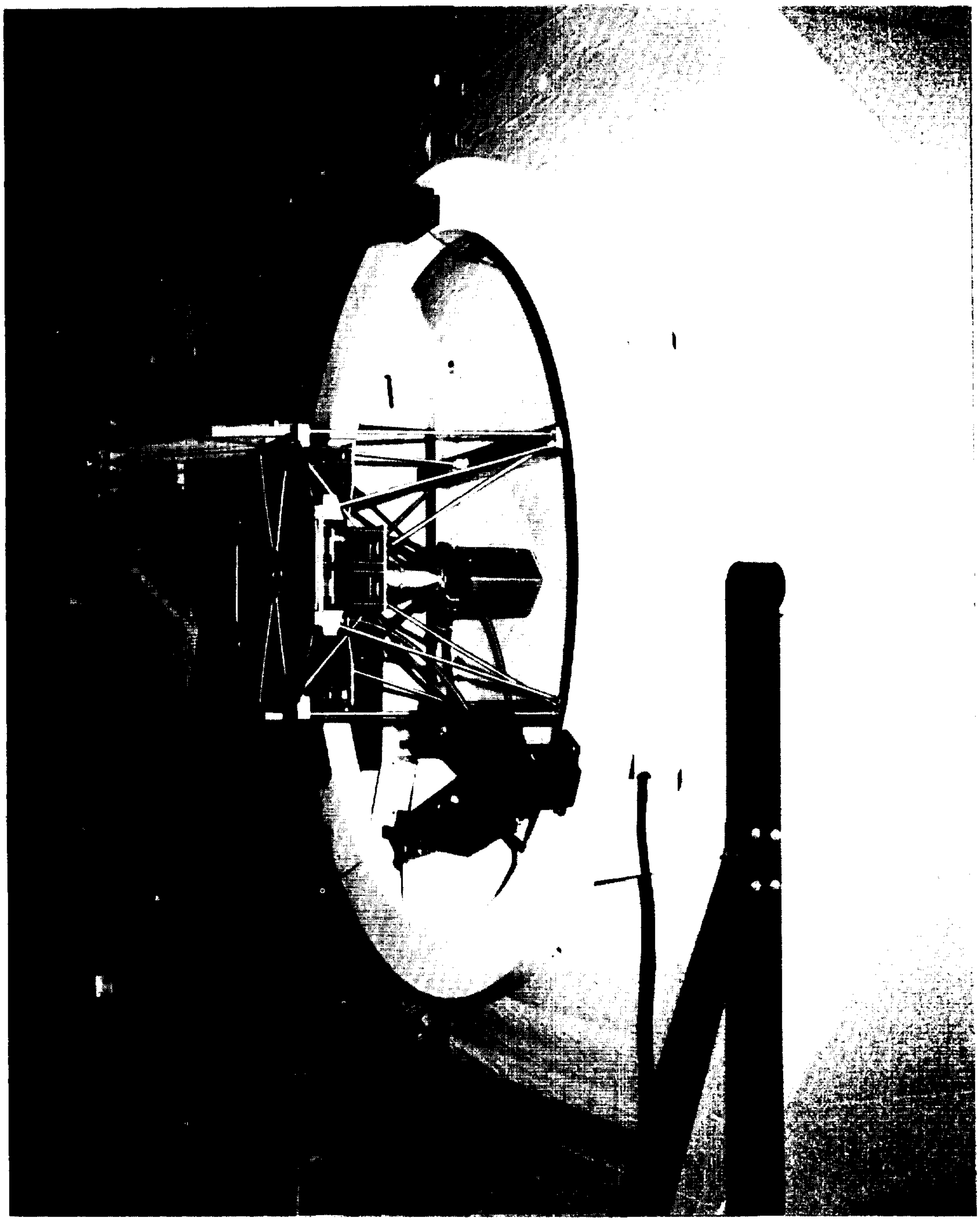

Figure 6: AFIS Ingtegrated with TPDM on OMV Mock-up.

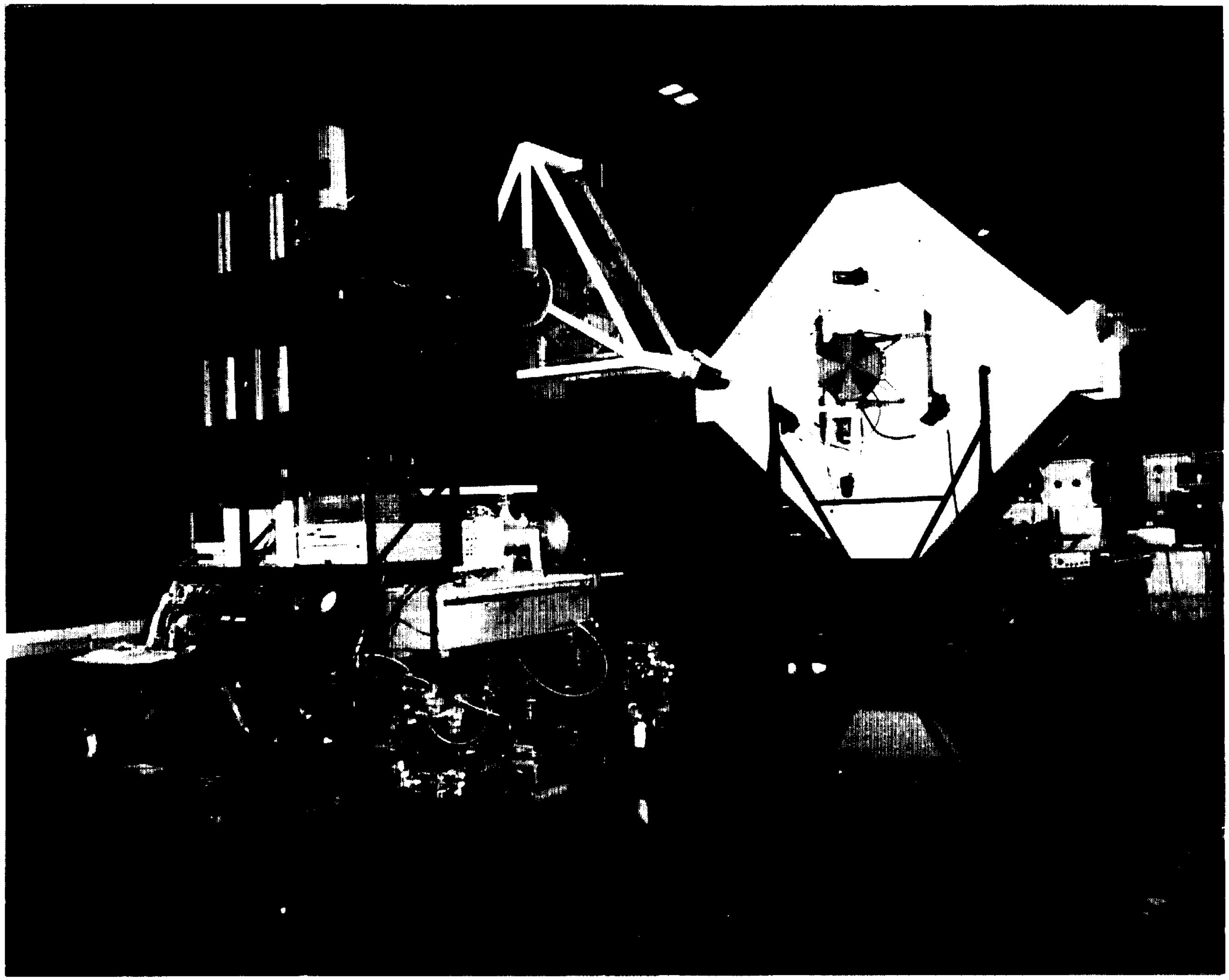

Figure 7: Demonstration Docking and Fluid Transfer in Robotics Facility.

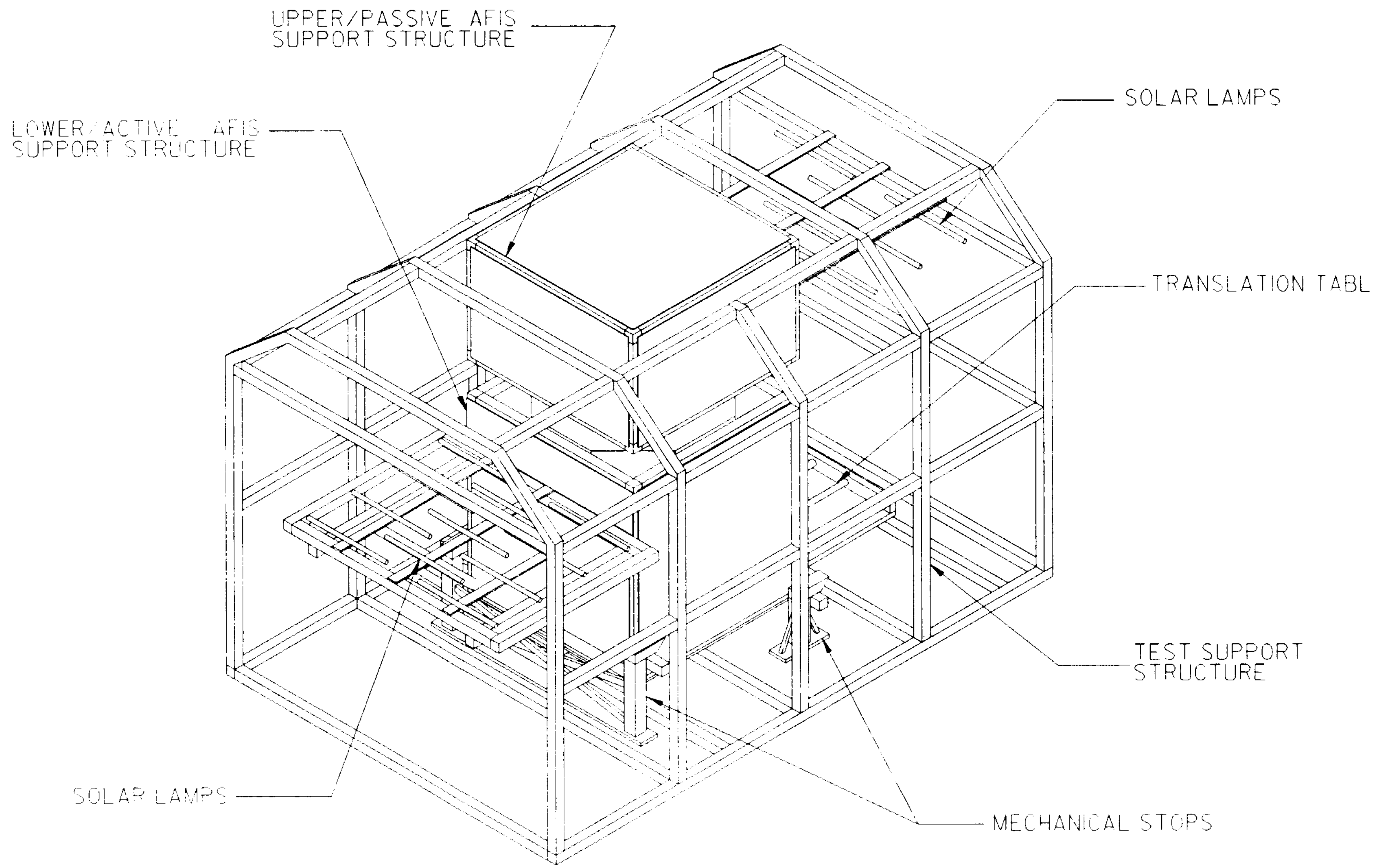

Figure 8: AFIS Thermal Vacuum Test Hardware with AFIS ready for Engagement.

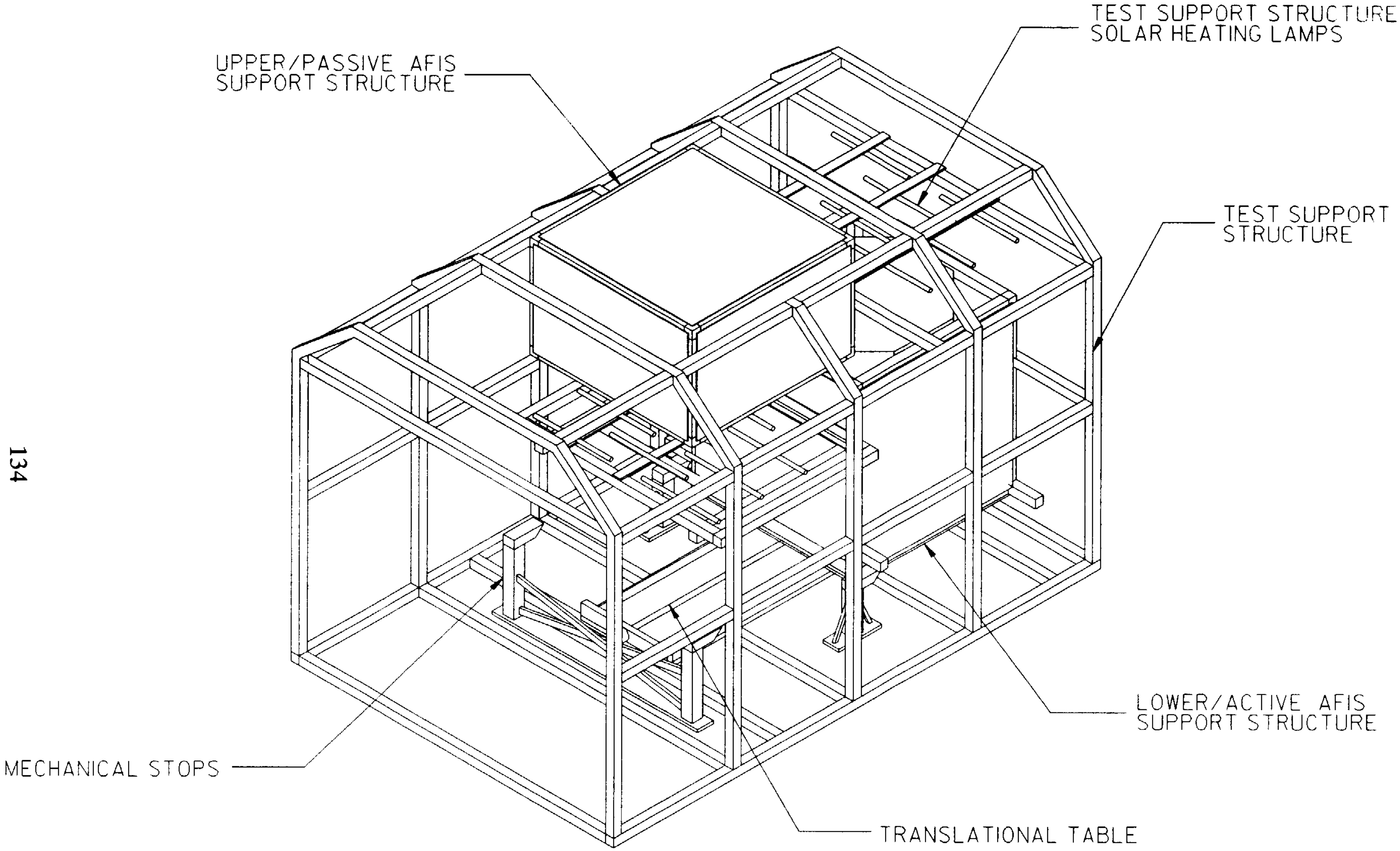

Figure 9: AFIS Thermal Vacuum Test Hardware with AFIS in Heating/Cooling Position.

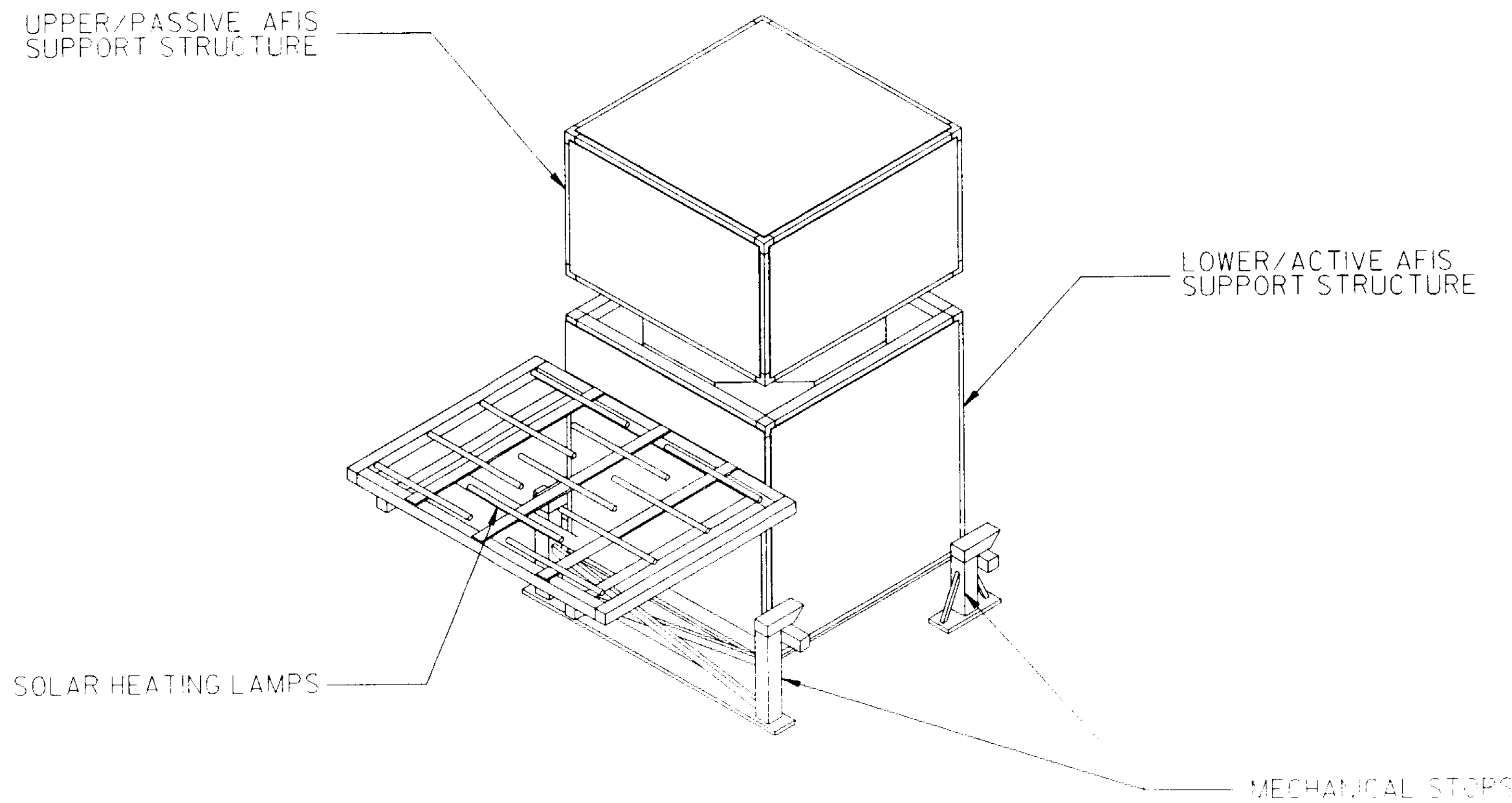

Figure 10: AFIS Support Structure.